PRACTICAL CASE OF RAPID PROTOTYPING USING GAS METAL ARC WELDING

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SUMMARY

To prove the viability of 'Rapid Prototyping using Fusion Welding' the author presents an example of a component created using this process. At this stage of the work, the process is not yet completed thus some of the modules that are part of this process were generated artificially. This paper will present the following sections: 1) a basic idea of how the process works, 2) description of each step in the process, 3) software/hardware used, 4) how each module was performed on the creation of this example, 5) the resultant shape and values, 6) deviations from the planned shape and 7) some conclusions.

INTRODUCTION

Very succinctly, the main objective of this work was to use a CAD package to draw a component and then "print" it in 3D using metal as base material. The "printer" being an Industrial Robot and the "ink" will be the filler material used in the robot arc welding process. That is, the robot should deposit metal in layers according to the shape drawn in the CAD system.

THE TECHNIQUE

The steps involved in this process were:

a) a CAD package was used to generate the component's shape
b) a program that reads the CAD file and transforms it into a Robot program in ARLA Language was written
c) a simulation package to check the viability of the robot program was used
d) an Off-Line programming routine was used to compile and download the ARLA program to the robot
e) the program was run to build up the component in layers using GMA welding

THE HARDWARE AND SOFTWARE USED ARE DESCRIBED BELOW

a) The CAD system used was AutoCAD[*] release 12
b) The Robot Simulation Package used was WorkSpace[**] 3.1 from Robotic Simulations, Ltd
c) The ARLA Compiler used was Off-Line Programming[***] 3.0 (OLP3) from ABB Robotics

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[*] AutoCAD is a registered tradename of AutoDesk
[**] WorkSpace is a registered tradename of Robot Simulations, Ltd
[***] OLP3 is a registered tradename of ABB Robotics

d) The computer used to run all of these software modules was an industrial PC 486/66-16Mb RAM from Blue-Chip
e) The robot used was an IRB2000 from ABB
f) A turn table was used which allows only 0 or 90 degrees tilt

HOW EACH MODULE WAS PERFORMED

AutoCAD was used due to its simplicity, ease of use, and ability to run on a Personal Computer. Any CAD system would be accepted as far as it is able to store the component's data as a DXF file format.

Having generated a solid shape using AutoCAD the individual layers of weld metal must be defined by creating the corresponding robot trajectory. In order to achieve this a programme has been written in 'C' language to slice the structure. Slicing is achieved by automatically analysing the component into primitive shapes based on cones, cubes, revoluted shapes, extruded shapes or 2D arcs and lines. The users determines the build up sequence, the orientation is determined by the software. Sequence commands and weld parameters are stored in an accompanying definition file. Programmes for the robot path and operating parameters are produced in the native language of the robot (i.e. ARLA in this case) and downloaded via a serial link from the Off-Line computer to the robot controller.

For the initial trials an alternative approach was adopted. The AutoCAD drawing was created in individual arcs and the data of the shape, dimensions and other process parameters were written in an EXCEL[****] spreadsheet.

This means that there is no need to translate anything but reading arcs. It is important to point out that a circle is an arc with 360 degrees and the reason for using arcs instead of circles was that a circle has no beginning and no end while an arc has a well defined starting point and ending point. The time that the robot takes to go from one layer to the next (up movement that takes around about 0.2 seconds), the robot continues depositing metal at this point which means that at the start point of the arc the thickness of the component will be larger. Therefore, arcs with 359 degrees were used instead of 360 degrees to avoid that problem.

It was decided that the shape of the component would be a 'vase' with a sinusoidal outer profile, as shown in Fig. 2. The vase was created in AutoCAD using arcs instead of solid primitives, (where each arc was one deposition layer to build up the component). Because of lack of components' information related to some welding parameters like the height of each layer, the shape drawn in AutoCAD needed to be modified after preliminary welding trials. If the component had been drawn with a solid primitive this would be easy to edit and change, but because the component was made up of 124 arcs this was a difficult and time consuming task and the use of a spread sheet gave much more freedom when changing the parameters. For example, average radius, height of each layer or height of the vase were created in the spread sheet. Each time a value was changed all the arc values (centre, radius, initial angle, finishing angle) were changed automatically instead of changing one by one (as was necessary in the CAD system). It was also possible to make a chart of the radius values (which gives the outer profile of the VASE) and this shows if the shape matches the desired dimensions.

The use of the spread sheet also gave the opportunity to calculate the operating variables involved in the build up of the component. For example, the time each layer takes to be built, the total time of the component build up, the quantity of material deposited and its weight.

[****] Excel is a registered tradename of Microsoft

After finding the desired value for each parameter, an ARLA robot program was generated. Work Space 3.1 was used as the robot simulation package to check the validity of the ARLA program. This task was necessary to check the existence of crashes with any component of the workcell and also to see if the program generated was going to do what was expected.

Off-Line Programming software version 3 (OLP3), was then used to compile and download the ARLA robot program into the robot.

After the robot program had been downloaded, some dummy runs of the program were performed to make sure that the task could be completed without any major problems.

Although a turn table was part of the work cell it was not used because it was not possible to control its speed from the robot controller. Instead, the Robot was used to make the arcs.

SOME INTERESTING VALUES

The planned component was 123 layers high and each layer was predicted to be 1.5 mm in height. This means that the component was expected to be 184.5mm high. But because there was a stand off increase of 4mm during welding, the deposition rate fell and the finished height was 4mm shorter (only 180.5mm). The diameter of the last layer was planned to be 103.82mm. The maximum radius was 67mm and this was at one third up from the bottom of the component. This major arc took 84.18 seconds to weld. The minimum radius was 48mm and this was at about 20% up from the base of the VASE. This shortest arc took 60.3 seconds to complete. These values are very important because the welding pool takes time to cool down and if one layer is deposited over another layer which is still very hot the resultant quality is very poor. Therefore, there is a minimum radius to be considered.

Layers	123 x 1.5 mm each	
Height	180.5 mm (should be 184.5)	
Diameter	103 mm (should be 103.82)	(Last layer)

All possible values were recorded during this trial and were calculated. The welding parameters were calculated and tested before starting this experiment. The values described below were the average values. The only value that didn't change during the experiment was the welding speed.

Wire Feed Speed	3.3	(Average value)
Voltage	16 V	(Average value)
Current	84 A	(Average value)
Welding Speed	300 mm/min	(Average value)

In the spread sheet, there was a column with the circle length of each layer (arc) and it was possible to calculate the total time expected per layer. The time that the robot takes to go from one layer to the next one was not taken into consideration and so the total time taken was 116 seconds more than the expected.

Start	1:00:40 PM	
Finish	3:30:30 PM	
Expected	2:27:54	
Total	2:29:50	(116 seconds more)

When the component was started there was a stand off of 13mm and by the end this was 4 mm larger. This means that the deposition height of each layer was not 1.5mm as planned but just under this value. This difference is analysed and assessed later on in this paper as well as all the other deviations in shape from those planned.

Stand off	Initial	13 mm
	Final	17 mm

At the end of the experiment, the slag and spatter was weighed and it was found to be about 40g. This was measured to check if the planned weight was correct. The weight of the material used (Mild Steel) was known and the diameter and length of the wire as well. Therefore, it was possible to calculate the planned weight which was found to be 2.54 Kg.

The slag & Spatter was estimated to be about 40g

DEVIATIONS FROM THE PLANNED

The component was examined to check the quality of the final product, deviation from the planned shape and integrity.

Radiography was carried out and this showed some porosity in the critical part of the VASE which is where the radius is shorter and upwards. This can be solved by changing the welding parameters. It is important to point out that the stand off was increasing from layer to layer and this may also explain some porosity.

A high resolution image processing measuring system was used to measure the exact dimensions of the component. The result is shown in Fig. 1.

Table 1, column (a) shows the comparative measurements taken using the image processing system for each direction, where A is the diameter of the top layer, B is the diameter of the arc with the largest radius, C is the diameter of the bottom layer and D is the height of the VASE. These tables contain two columns to differentiate the values in X and Y axis. This was done to check the concentricity of the VASE.

Column (b) contains the planned diameters for the same sections measured by the image processing measuring system. And column (c) the deviations between the real and the planned diameters.

Table 1

	(a) Measured values No. 1	(a) Measured values No. 2	(b) Planned values No. 1	(b) Planned values No. 2	(c) Deviations No. 1	(c) Deviations No. 2
A	107.30	107.86	109.56	109.56	2.26	1.70
B	138.80	137.85	138.00	138.00	0.20	1.15
C	115.90	115.64	116.10	116.10	0.20	0.46
D	179.00	179.20	184.50	184.50	5.50	5.30

millimeters

Table 2 shows the thickness (or value E in the Fig.1), recorded by the image processing system, the planned and the deviations. The thickness was measured in four different places and the key letters correspond to the position of measurement as indicated in Fig. 1.

Table 2

Position	F	G	H	J
Measured	5.00	5.08	4.83	4.85
Planned	5.00	5.00	5.00	5.00
Deviation	0.00	0.08	-0.17	-0.15

millimeters

The errors shown are very small which makes the process very acceptable in terms of accuracy. It is important to point out that the thickness was measured in the most critical part of the VASE which is where the radius is shorter.

SOME CONCLUSIONS

a) component is 1mm out of concentricity

b) there was slag and spatter. The reason is in the welding parameters used

c) stand off was not constant. It needs adjustment and is also a welding parameter

d) if a welding robot was used, the resultant smoothness of the jug would be the same

e) the shape of the VASE was one of the reasons for the stand off variation

f) the welding quality also changes with the shape of the component

g) a welding system tends to loose quality after a certain time, which means that the process should be stopped from time to time. This also would help to cool down the component provoking a better deposition

h) the 116 seconds difference is due to the robot moving from one layer to the next one. 123x0.5s at 300mm/m -> 0.3 x 123 = 36.9 seconds + (START TIME + STOP TIME) x 123

i) the VASE base should be weighed before starting welding and again at the end. The exact quantity of material deposited can then be calculated.

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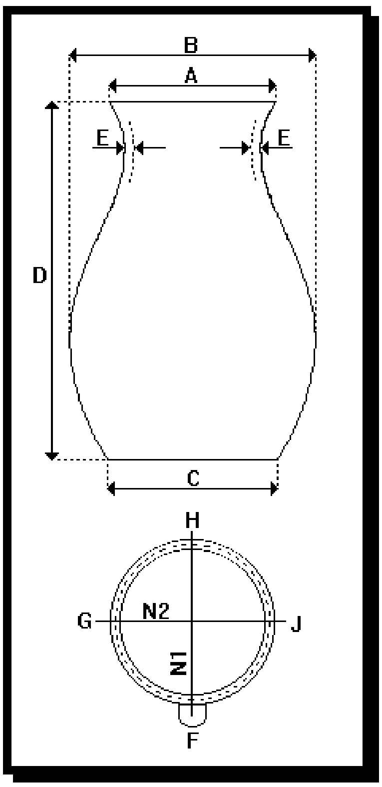

Figure 1 Vase nomenclature


Figure 2 Vase produced in metal using this process